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Art. XXIV.—*On a Volcanic Agglomerate, containing glaciated pebbles, at Kangaroo Gully, near Bendigo.*

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(With Plate XXXII.)

[Read 11th December, 1913.]

Introduction.

This communication is concerned with the nature and origin of a remarkable rock outcropping in Kangaroo Gully about four and a-half miles S.W. of Bendigo. My attention was first called to it, and some of its peculiarities described to me by one of my former students, Mr. E. C. Dyason, B.Sc., B.M.E., towards the end of the year 1905. In his company and that of Mr. H. S. Whitelaw, of the Geological Survey of Victoria, I visited and examined the locality in January, 1906. A second visit was made by Mr. Dyason and myself in March, 1906. In 1907 and again in 1911 I revisited the area, and completed the field observations recorded below. I have delayed publication in the hope that further field work and reflection might enable me to give a satisfactory explanation of the origin of the occurrence. A completely satisfactory solution of all the problems has not occurred to me, but as the sections exposed in the gully are becoming more obscure, I now place the facts on record before the opportunity for other geologists to examine the exposures in the field is lost.

Previous Literature.

In 1873 Mr. Reginald Murray made a sketch geological map of the Sandhurst (Bendigo) district, which included the area under discussion. The alluvial gold-bearing deposits of Kangaroo and Opossum Gullies are indicated on all copies of the map, but the copy in the geological department of the University shows no indication of the conglomerate or agglomerate. A copy in the Geological

Survey Office at Bendigo, however, shows the boundaries of the conglomerate approximately defined.

The only written account of the conglomerate I have been able to find occurs in the Report on the Bendigo Gold Field, page 6, by Mr. E. J. Dunn, F.G.S., published by the Geological Survey of Victoria in 1892, and a second part in 1896. As Mr. Dunn's description, though important, is brief, I record it in full. It is headed, "Glacial Conglomerate":—

"On the west side of Kangaroo Gully, and opposite Opossum Gully, an outlier, a few chains in length, and from one to two chains in width, of conglomerate that is referable to the same age as the Wild Duck Creek conglomerate, occurs; it does not appear to be of any great depth, and in age may be of Permian or later date. In a more or less clayey matrix, in part rudely stratified, and in indurated fine gravel are well rounded masses of quartzite derived from Devonian conglomerates, hard grey sandstones in angular blocks, small fragments of schist, etc., the pebbles and fragments with the larger axes as frequently nearly vertical as horizontal. Veins of pale yellow chalcedony occur, penetrating the clayey matrix; no other outlier was noticed in the vicinity of a similar character. The conglomerate is very distinct from and in no way to be confounded with the tertiary conglomerates; it is the last vestige of what may have been a very extensive deposit."

Mr. F. L. Stillwell, M.Sc., in a paper on the monchiquite dykes of the Bendigo goldfield. Proc. Roy. Soc., Vic., Vol. xxv. (New Series), Part 1, 1912, p. 9, in discussing their age, refers to one dyke cutting the conglomerate of Kangaroo Gully.

In view of the volcanic nature of the matrix of this occurrence at Kangaroo Gully, it is interesting to note that some of the earlier geologists in South Africa described the Permo-Carboniferous glacial comglomerate (the Dwyka conglomerate) as of volcanic origin. A. G. Bain, in Q.J. Geol. Soc., 1845, p. 315, described the rock as a claystone-porphyry, and believed it to be the product of an enormous volcano. D. Draper, in Q.J. Geol. Soc., Vol. 50, 1894, pp. 554-555, discussed the origin of the Dwyka conglomerate, and quoted a letter from Dr. G. A. F. Mobengraff, in which the latter stated that he had studied the rock "in situ," and by microscopic sections. He said: "The Dwyka conglomerate gives me the impression of a volcanic tuff (I mean a probably Permian diabase-tuff) full of fragments of older rocks."

Tho hypothesis of the volcanic origin of the Dwyka conglomerate is now, I believe, entirely abandoned in favour of a direct glacial origin. Rock sections which I have made from material collected by me at Riverton, near Grahamstown, and elsewhere in South Africa, certainly contain pebbles of igneous rocks, but the matrix is free from volcanic material, and has the angular and typical characters of a normal glacial conglomerate.

Position of the Deposit.

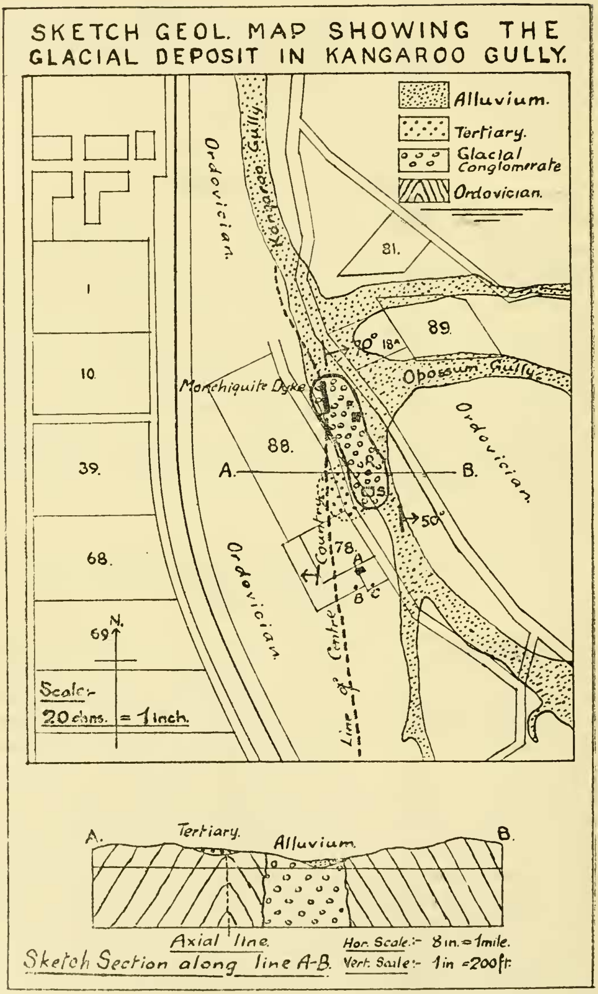
The deposit is best found by going about $3\frac{1}{2}$ miles about S.W. from Bendigo along the Bendigo Creek to its junction with Kangaroo Gully at Kangaroo Flat. A further $1\frac{1}{8}$ miles almost due south along Kangaroo Gully, brings one to its junction with an eastern tributary called Opossum Gully, and the north end of the deposit in question is seen in section on the west bank of Kangaroo Gully, about 120 yards south of its junction with Opossum Gully. The outcrop is roughly elliptical (see sketch map), the longer axis of the ellipse coinciding almost with the bed of the creek occupying Kangaroo Gully. The deposit is about 400 yards in length from north to south, and the width varies from about 40 to 70 yards.

Nature of Outcrop of Deposit, and Relations of Surrounding Rocks.

In places the deposit is masked by recent river alluvium, but generally the rock outcrops at the surface above creek level, and has been exposed probably as the result of alluvial mining. One or two small gullies running east and west cut through the deposit on the west side of Kangaroo Guly, and in one of these the deposit is seen in contact with vertical Ordovician slates and sandstones. The junction of the two rocks is almost vertical, and both rocks are overlain unconformably by recent alluvial material or hill wash.

Since Mr. Dunn's examination of the deposit two parties of miners, presumably under the belief that the deposit was superficial, and that alluvial gold would be found below it, have sunk two shafts and a bore into the deposit.

The most northerly shaft (shown at F on map), and referred to in this paper as the main shaft, is 2 feet by 5 feet in cross section, and 24 feet deep.



SKETCH GEOL. MAP SHOWING THE GLACIAL DEPOSIT IN KANGAROO GULLY.
Alluvium.
Tertiary.
Glacial Conglomerate
Ordovician.
Ordovician.
Kangaroo Gully
81.
89.
1
10.
39.
68.
69
N.
Monchiquite Dyke
Opossum Gully
Ordovician.
88.
A.
B.
50°
Country
78.
Ordovician.
Line of Centre
Scale:-
20 chns. = 1 inch.
A.
Tertiary.
Alluvium.
B.
Axial line.
Sketch Section along line A-B.
Hor. Scale:- 8 in. = 1 mile.
Vert. Scale:- 1 in = 200 ft.

Fig. 1.

S.S.E of the main shaft a bore was put down at R on map to a depth of 104 feet, by two miners named Murphy and Busst, while still further S.S.E. at S. on the map, another shaft, sunk by other miners, named Jenkins and Bielski, penetrates the deposit for 55 feet, and by boring a further 10 feet a depth of 65 feet was reached.

All these shafts and bores continued in the deposit to the lowest depths reached, when sinking was abandoned.

The relations of the deposit to the Ordovician rocks is peculiar. The shallow section in the E. and W. gully, cutting the deposit shows an almost vertical contact between the two formations. Further evidence of a similar kind occurs near the bore at R on the map. Eighteen yards S.W. of the bore Ordovician slates and sandstones outcrop on the west side of the gully. They strike north 12 deg. west, and dip exactly at 80 deg. Since the bore penetrated the deposit for 104 feet, without reaching the Ordovician, it follows that the angle of contact between the deposit and the Ordovician must exceed 60 deg. The average strike of the Ordovician rocks near the deposit is north 10 deg.-20 deg. west. On the west side of the gully the rocks dip west at high angles, and on the east side they dip east at from 50 deg.-70 deg., as shown on map. An anticlinal fold or line of centre country therefore runs almost parallel with Kangaroo Gully, and the north-west part of the outcrop of the deposit crosses the axial line. This line is evidently the southerly continuation of the Bird's line of reef. The shaft of the Bird's mine lies 15 deg. west of true north from the deposit in Kangaroo Gully. Along this axial line a monchiquite dyke cuts the deposit as shown on the map at the north-west part of the outcrop. The dyke is about 1 foot wide, and has been traced on the surface for about 30 yards. The strike of the dyke is north 14 deg. west, and the dip is nearly vertical, but really at a high angle to the east. It is to be noted that the area occupied by Ordovician rocks on the map is left unshaded.

Some patches of Upper Tertiary sands, clays, and ironstones occur to the south-west of the deposit, as shown on the map, and are also indicated at the points A and B on the map. A is a small patch exposed in a dam; B is ironstone from a small dam, while C represents a shaft sunk 40 feet in Ordovician sandstone.

Distribution and Nature of Pebbles in the Deposit.

The vertical section exposed in the main shaft at F on the map shows from above downwards.

Silt, 18 inches.

Gravelly wash, part angular, part rounded—2 feet—2 feet 6 inches.

Volcanic agglomerate, with a few large pebbles and scattered rounded quartz grains—19 feet—19 feet 6 inches.

At shaft S, sunk by Jenkins and Beilski, the surface material contained many pebbles, but the material brought up in sinking the shaft consists almost entirely of fragmental volcanic material with small quartz grains scattered through it. Some fragments of altered Ordovician sandstone occur, and one of these is described later. It was reported to me that a large boulder was found near the bottom of the shaft, but of this I have no personal knowledge. The surface outcrops of the deposit generally show no bedding or sorting of the material, and contain abundant pebbles, some angular, some rounded, and some facetted, of various rocks, including quartzites, shales, and vein quartz. The pebbles occur with their longer axes irregularly disposed. In places rude bedding of the material is indicated principally by bands of varying colour. Mr. Dunn has referred to the occurrence of veins of chalcedony in the deposit. I found one such piece, evidently formed since the deposit, filling a cavity in the material and showing concentric banding, indicating deposition from solution.

The distribution of the pebbles suggests that they are only abundant near the surface. Mr. Dyason and myself, however, descended the main shaft at F on the map, and found, embedded two inches in the wall of the shaft 19 feet below the surface, a quartzite pebble, which is polished and facetted and almost certainly of glacial origin. Minute, rounded and angular quartz grains are not uncommon in the volcanic matrix wherever we examined it. Among the quartzite pebbles in the superficial part of the deposit a number were found which, while rounded, were also polished as if by glacial action, while one shown in Plate xxxii., Fig. 1 is a quartzite pebble, not only definitely facetted but showing on one face distinct glacial striations. There can be no doubt therefore that Mr. Dunn was right in describing the pebbles as glacial, although he did not obtain evidence, such as is described above, of facetting and striation among the pebbles.

Petrographical Characters of the Matrix of the Deposit.

As soon as I saw the deposit, even the superficial portion, I recognised the great resemblance of the matrix to an ultra-basic volcanic agglomerate. In hand specimen it is in some ways comparable to the material filling the volcanic neck at the Pennant Hills, near Sydney, New South Wales.

The microscopic and chemical evidence, it will be seen, entirely supports this view of its origin. As an example of the matrix at the surface one may cite an agglomerate (Plate xxxii., Fig. 2), occurring 40 yards south of the north end of the deposit. Glacial pebbles occur in this material. Under the microscope, (Sections No. 1009), there are seen large fragments of angular quartz, more or less corroded, and of Ordovician shale. Some secondary quartz filling cavities in the rock or replacing primary minerals can also be distinguished. The bulk of the rock consists of larger and smaller fragments of a very basic volcanic rock embedded in a finer volcanic paste or cement. Both fragments and cement are much altered, so that the rock is stained and impregnated with red oxide of iron.

The minerals present in the rock are olivine, now represented by pseudomorphs in serpentine, biotite in long lath-shaped crystals, now bleached and partially altered to hydromica, augite (?), possibly represented by granular iron-stained crystals, magnetite or ilmenite, and a base which is almost isotropic, and may represent glass or possibly analcite. The rock is essentially an olivine-biotite-monchiquite agglomerate, with fragments of quartz and Ordovician sediments. It resembles closely the monchiquite dyke which intersects the deposit, but differs mainly in the paucity or absence of augite.

As examples of the nature of the deposit below the surface, the following specimens may be described :—

Specimen from the main shaft (Section No. 1010), (Plate xxxii., Fig. 3). For chemical analysis, see below.

The rock is much altered. Porphyritic pseudomorphs in serpentine after olivine are abundant, the ground-mass showing granules and prismatic purple needles of titaniferous augite, and a colourless to brown isotropic matrix, which may be glass or analcite. Small water-worn and angular quartz grains occur, and are corroded, and some show a reaction rim, including minute prismatic needles, possible of hornblende. Some secondary silica occurs in the form of quartz and chalcedonic infillings or replacements. The rock is essentially an altered olivine monchiquite, with larger and smaller foreign pebbles.

Fragments from Bore at F, occurring round the bore hole, depth unknown (Section No. 1020).

This rock is essentially similar to the last described. It is porphyritic and hyalopilitic, contains phenocrysts of altered olivine, and in the ground-mass purple prismatic titaniferous augite, with extinction angle of 40 deg.-46 deg., abundant minute magnetite or ilmenite crystals, and the remainder consists of brown isotropic material, probably glass. One corroded fragment of quartz is embedded in the rock. The rock is a fragment of an olivine monchiquite.

The monchiquite dyke cutting the deposit at its north-west end has the following microscopic characters, (Section, No. 1011), (Plate xxxii., Fig. 4). For chemical analysis, see below.

The olivine crystals occur as serpentine pseudomorphs. Abundant faintly purple augite needles, probably titaniferous, extinction angle 40 deg.-46 deg., and lath-shaped brown biotite crystals occur, but magnetite is practically absent. Some of the cavitites in the rock are lined with secondary chalcedony, and filled with pale serpentine. The ground-mass is colourless and isotropic, and may be glass or analcite.

The rock is an Olivine-Monchiquite.

From Jenkins and Bielski's shaft (S. on map) a large fragment of rock was found in the heap surrounding the shaft. Its nature was not at first recognised, but the chemical analysis quoted below, and the evidence in section under the microscope show that it is a fragment of Ordovician sandstone, which became embedded in the volcanic material.

In Section No. 1014, it consists of angular and sub-angular quartz fragments in a felspathic and micaceous cement. A band of argillaceous material partly iron-stained, and partly changed to chlorite occurs in one part of the section. The rock is an altered felspathic sandstone.

The Chemical Characters of the Rocks.

Analyses of the fragmental rock from the main shaft were made by Mr. T. H. Plante, B.Sc., and of the monchiquite dyke, and the fragment of ordovician sandstone from Jenkins and Bielski's shaft by Mr. H. C. Richards, M.Sc., Mr. E. O. Thiele, M.Sc., redetermined for me the alkalies in the fragmental rock from the main shaft. All these gentlemen were, at the time the analyses were made, advanced students in the Geological department of the University. Their results are as follow :—

A.—Analysis of volcanic fragmental rock from main shaft, by T. H. Plante, B.Sc. ; alkalies in above by E. O. Thiele, M.Sc.

B.—Analysis of monchiquite dyke, penetrating deposit in Kangaroo Gully, by H. C. Richards, M.Sc.

C.—Analysis of Ordovician fragment, from Jenkins and Bielski's shaft, by H. C. Richards, M.Sc.

D.—Analysis of monchiquite, from Central Red, White and Blue mine, Sheepshead line, by F. L. Stillwell, M.Sc. (Quoted from Proc. Roy. Soc., Vict., Vol. xxv. (new series), Part i., 1912, p. 4.)

	A	B	C	D
SiO_2 -	41.42	41.15	64.87	40.92
TiO_2 -	6.58	5.62	2.41	6.57
Al_2O_3 -	14.86	10.54	13.82	11.34
Fe_2O_3 -	13.36	13.21	3.95	.54
			FeO = 3.50	FeO = 12.96
CaO -	2.72	10.70	tr.	9.28
MgO -	0.38	7.28	1.23	7.78
				MnO = 0.13
K_2O -	3.30	2.18	5.70	1.94
Na_2O -	10.20	0.99	1.78	3.27
				P_2O_5 = 0.51
H_2O- -	5.42 (H₂O − and H₂O +)	7.25	Loss on ignition = 2.40	0.64
H_2O+ -		2.15	-	1.77
CO_2 -	2.40	0.60	-	2.82
Total -	100.64	101.67	99.66	100.47

Certain comments on the analyses are necessary. In the first place both A and B are very altered rocks. This may be regarded as explaining the high-water content (mostly in the serpentine), and the amount of CO_2 present in the rock. As the rocks were so altered, all the iron present was determined as Fe_2O_3. Allowing for these points, it will be noticed that there is a close resemblance in the analyses of the monchiquite dyke from Kangaroo Gully analysed by Mr. Richards, and that of the Central Red White and Blue mine analysed later by Mr. Stillwell.

The comparison between analyses A and B brings out some interesting points, and one very puzzling one. The percentages of silica, titanium oxide, and ferric oxide in the two rocks are so similar as to leave no doubt that the rocks were originally essentially similar. This implies that the fragmental rock from the main shaft had originally the composition of an olivine-monchiquite. The microscopic evidence quoted above entirely supports this conclusion. However, the subsequent alteration of the two rocks has apparently been different. Whereas the content of lime, magnesia, and the alkalies in B, the monchiquite dyke, is quite normal for such a rock, the proportions in the fragmental rock are absolutely abnormal, the alkaline earths totalling only three per cent., while the alkalies total thirteen and a-half per cent. This implies the removal of the bulk of the alkaline earths present in the fresh rock, and the introduction of about 10 per cent. of alkalies, principally soda. At first I refused to credit the results of the analysis. Mr. Plante, however, determined the alkalies twice, and obtained a total of 12 to 14 per cent. for the determinations. At a later date Mr. Thiele re-determined the alkalies, and his results are included above. The microscopic examination fails to indicate in what mineral form the alkalies are present in the rock. There are no felspars, and while analcite may be present there is nothing in the appearance of the section to suggest its presence in large quantity. I am not aware of any similar type of alteration in an igneous rock having been previously recorded. There seems to be no doubt of the original nature of the rock, and of its present composition; the alteration has occurred, but I am quite unprepared to suggest the chemical and mineralogical changes by which the alteration has been effected.

The Origin and Age of the Deposit.

The evidence of the mode of occurrence of the deposit shows a probably vertical contact with the Ordovician, while the microscopic and chemical evidence shows that the bulk of the material, especially below the surface, consists essentially of fragments of an ultrabasis volcanic rock, a monchiquite agglomerate. The relations are suggested in the sketch section accompanying the geological map. (Figure in text.) Further, the chemical and miscrocopical evidence shows the closest relations between the agglomerate and the monchiquite dyke penetrating it. Elsewhere[1] Mr. Stillwell has suggested a correlation between the monchiquite dyke of Bendigo and elsewhere in Victoria, and some of the limburgites of the Macedon district,[2] which are not older than mid-Kainozoic, and

1 Stillwell *op. cit.*

2 Skeats and Summers. Geology and Petrology of the Macedon District, Bulletin 24. Geol. Survey of Victoria, 1912.

may be younger. If this correlation is correct, and it seems probable, the agglomerate of Kangaroo Gully, from its resemblance to the monchiquites, would be referred to the same age, i.e., not older than the mid-Kainozoic.

The evidence of the glaciated pebbles in the deposit, however, is important. We know of only one glacial period in Victoria, and that is of Permo-Carboniferous age. Two alternative explanations of this remarkable association of glacial pebbles in a monchiquite agglomerate suggest themselves, but neither is put forward with any great confidence.

On the one hand we may picture the agglomerate as at least of Permo-Carboniferous age, possibly older. The passage of the Permo-Carboniferous ice sheet over the area may have involved the ploughing up of the upper part of the agglomerate, and glaciated pebbles, with finer quartz grains, might in this way be embedded in the upper part of the deposit, where, in fact, they are most plentiful. As against this view we have the negative evidence that no other volcanic rocks of this character of Permo-Carboniferous, or pre-Permo-Carboniferous age, are known in Victoria, and the positive evidence that their known chemical and petrological analogies in Victoria are not older than mid-Kainozoic.

The alternative explanation is not without difficulties, but seems to me to be at any rate less improbable.

According to this view, one would picture the Bendigo Ordovician area partly covered by Permo-Carboniferous glacial conglomerate in mid-Kainozoic time. A volcano of explosive type reached the surface in Kangaroo Gully, bursting through the glacial conglomerate, and ejecting monchiquite agglomerate. Some of the glacial pebbles and finer material would be likely to become incorporated in this way in the agglomerate. Subsequent denudation of the area has removed all traces of the glacial deposit, except those pebbles which had become incorporated in the monchiquite agglomerate.

It may be suggested that the pebbles, while glacial, are derived not immediately from a Permo-Carboniferous glacial deposit, but have been handed down to a Kainozoic or recent river gravel, and have become incorporated in the agglomerate in comparatively recent times. This view I have considered and rejected, as a close examination of adjoining Kainozoic and recent river gravels showed a complete absence of glaciated pebbles, and a marked difference in lithological characters. On the whole, but with considerable diffidence, I think that the least unlikely hypothesis is the second one stated, that the deposit is essentially a Kainozoic monchiquite agglomerate, formed from an explosive type of volcano, which, bursting through a deposit of Permo-Carboniferous glacial conglomerate, incorporated a certain proportion of glaciated pebbles and finer detritus among the volcanic ejectamenta, and that subsequent denudation of the area has removed all the glacial material except where the neck of the volcano is now exposed to view in Kangaroo Gully.

Summary.

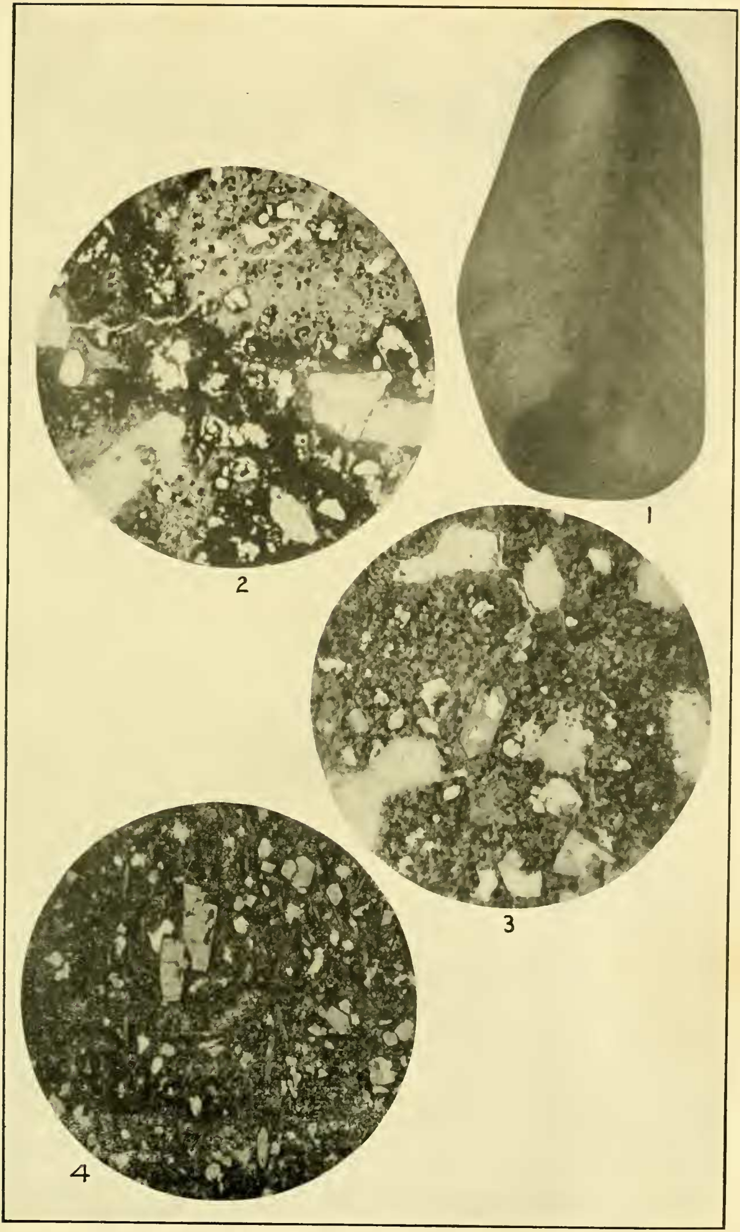
A volcanic agglomerate, containing glaciated pebbles, and invaded by a monchiquite dyke occurs at Kangaroo Gully, near Bendigo. It junctions nearly vertically with Ordovician slates and sandstones, and appears to be the outcrop of a volcanic pipe, elliptical in outline, and stretching N.N.W. and S.S.E., about $\frac{1}{4}$ mile long, and 40-70 yards broad. The pipe has been penetrated by shafts and bores to 104 feet. The bulk of the material consists of monchiquite agglomerate similar petrologically to the dyke which penetrates it. Chemical analyses show some similarities to the dyke, but it is abnormally low in alkaline earths (3 per cent.), and abnormally high (13.5 per cent.) in alkalies. These results appear to be due to obscure subsequent alteration of the rock.

The agglomerate, especially near the outcrop, contains abundant pebbles, some of which are definitely glaciated, and contains scattered grains of quartz, apparently throughout. After considering various alternative explanations of the mode of occurrence, it is suggested as not improbable that in mid-Kainozoic times explosive volcanic activity formed a vent, which penetrated a deposit of Permo-Carboniferous glacial material, and incorporated some glacial pebbles with its fragmental ejectamenta. Subsequent denudation removed all traces of glacial material, except where it was embedded in the neck of the volcano.

EXPLANATION OF PLATE XXXII.

Fig. 1.—Facetted and striated glacial quartzite pebble from outcrop of deposit in Kangaroo Gully. About $\frac{2}{3}$ natural size.

Fig. 2.—Photomicrograph, Section No. 1009, x 25 diameters. Agglomerate type of deposit, in which glaciated pebbles occur. The section shows angular and corroded quartz, and fragments of monchiquite and quartzite in a volcanic matrix. Forty yards south of north end of deposit.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